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# Development of geothermal energy utilization in Turkey: a review

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**Abstract**

Renewable energy is accepted as a key source for the future, not only for Turkey but also for the world. Turkey has a considerably high level of renewable energy sources that can be a part of the total energy network in the country. Turkey is located in the Mediterranean sector of Alpine–Himalayan Tectonic Belt and has a place among the first seven countries in the world in the abundance of geothermal resources. The share of its potential used is, however, only about 2–3%.

The main objective of the present study is to review the development of geothermal energy (GE) utilization in Turkey, giving its historical development and opportunities. GE is used for electric power generation and direct utilization in Turkey, which is among the first five countries in the world in geothermal direct use applications. Direct use of geothermal resources has expanded rapidly last 36 years from space heating of single buildings to district heating, greenhouse heating, industrial usage, modern balneology and physical treatment facilities.

Turkey presently has one operating geothermal power plant, located near Denizli City in Western Anatolia with an installed capacity of 20.4 $MW_e$ and an electrical energy production of 89,597 MW h in 2001. Recently, the total installed capacity has reached 820 $MW_t$ for direct use. The total area of geothermal heated greenhouses exceeded over 35 ha with a total heating capacity of 81 $MW_t$. Ground-source (or geothermal) heat pumps (GSHPs) have also been put on the Turkish market since 1998. Though there are no Turkish GSHP manufactures as yet, 207 units have been installed in the country to date, representing a total capacity of 3 MW.

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GE is a relatively benign energy source, displaying fossil fuels and thus reducing greenhouse gas emissions. So, it is expected that GE development will significantly speed up in the country if the geothermal law becomes effective.


*Keywords:* Geothermal energy; Electricity generation; Direct use; Heat pumps; Space heating; District heating; Greenhouses; Renewable energy; Sustainable development; Turkey

**Contents**



## 1. Introduction

National and international bodies use a variety of definitions for renewable energy. The Renewable Energy Working Party of the International Energy Agency set down the following definition: "Renewable energy is energy that is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources" [1].

Geothermal energy (GE) is the heat (thermal) stored in the earth (geo). It is the thermal energy contained in rocks and fluids (that fill the fractures and pores within the rock) in the earth's crust. The deeper one penetrates into the interior of

our planet, the hotter it gets: a continuous heat flow rises from the core to the surface, heating the rocks and groundwater [2,3].

With a rapidly growing world population, and ever-increasing environmental concerns, sustainable development has become an issue of crucial importance for mankind. Geothermal resources have the potential of contributing significantly to sustainable energy use in many parts of the world. Sustainable geothermal utilization involves energy production at a rate which may be maintained for a very long time (100–300 years). The production capacity of geothermal systems is quite variable and different systems respond differently to production, depending on their geological setting and nature. Therefore, comprehensive management is essential for the sustainable use of all geothermal resources. In other words, efficient management is required in order to avoid overexploitation, which mostly occurs due to lack of knowledge and poor understanding as well as in situations when many users utilize the same resource, without common management. Energy-efficient utilization, as well as careful monitoring and modeling, are essential ingredients in sustainable development. Reinjection is also essential for sustainable utilization of geothermal systems, which are virtually closed and with limited recharge [4].

In general, the GE resource base is large and well distributed globally. Geothermal systems have a number of positive social characteristics (they are simple, safe, and adaptable systems with modular 1–50 MW plants capable of providing continuous baseload, load following, or peaking capacity) and benign environmental attributes (negligible emissions of $CO_2$, $SO_x$, $NO_x$, and particulates, and modest land and water use). Because these features are compatible with sustainable growth of global energy supplies in both developed and developing countries, GE is an attractive option to replace fossil and fissile fuels [5].

GE has been produced commercially for over 80 years, and for four decades on the scale of hundreds of megawatts both for electricity generation and for direct use. The utilization of GE has increased rapidly during the last three decades. In 2000, geothermal resources have been identified in over 80 countries and there are quantified records of geothermal utilization in 58 countries in the world [6].

Geothermal resources using today's technology have the potential to support between 35,448 and 72,392 MW of electrical generation capacity. Using enhanced technology currently under development (permeability enhancement, drilling improvements), the geothermal resources could support between 65,576 and 138,131 MW of electrical generation capacity. Assuming a 90% availability factor, which is well within the range experienced by geothermal power plants, this electric capacity could produce as much as 1089 billion kW h of electricity annually [7].

Table 1 [5,8–10] shows the historical trends for geothermal power generation worldwide with the exception of the period during World War II, when the Larderello field was out of service. Italy was the first country to develop geothermal power commercially in 1914 at Larderello. Use of geothermal power has been exponentially increasing at about 8.5% per year since about 1920 [5]. Geothermally

Table 1
Historical trends for geothermal power generation worldwide by capacity [5,8–10]

| Year | $MW_e$ installed generating capacity | Notes |
|---|---|---|
| 1902 | 0.1 | Larderello, Italy field starts up. |
| 1915 | 1 | |
| 1920 | 10 | |
| 1930 | 20 | |
| 1935 | 20 | |
| 1942 | 130 | |
| 1942–1945 | 0 | World War II curtails production. |
| 1950 | 239 | Other countries begin production. |
| 1958 | 362 | Wairakei, New Zealand field comes on line. |
| 1960 | 368 | The first commercial-scale development tools are placed at The Geysers in California, a 10-MW unit owned by Pacific Gas & Electric. |
| 1965 | 558 | |
| 1970 | 715 | Cerro Prieto, Mexico on line 1973. Re-injection of geothermal fluids. Injection of spent geothermal fluids back into the production zone begins as a means to dispose of wastewater and maintain reservoir life. |
| 1975 | 1314 | |
| 1978 | 1447 | |
| 1980 | 2390 | The first commercial-scale binary plant in the US, installed in Southern California's Imperial Valley, begins operation. |
| 1982 | 2882 | |
| 1984 | 4164 | |
| 1986 | 4590 | |
| 1988 | 5420 | |
| 1990 | 5832 | |
| 1995 | 6798 | Growth in capacity due largely to Philippines and Indonesia after 1994. |
| 2000 | 7974 | Geothermally fueled electric power is generated in 21 countries. |
| 2005 | 11,398 | Projected |

fueled electric power is being generated in 21 nations as of February 2000; the installed capacity has reached 7974 $MW_c$ [9]. The electrical energy generated was 49.3 billion kW h/year, representing 0.3% of the world total electrical energy, which was 15,342 billion kW h in 2000. In developing countries, where total installed electrical power is still low, GE can play a significant role: in the Philippines, 21% of the electricity comes from geothermal steam, 20% in El Salvador, 17% in Nicaragua, 10% in Costa Rica and 8% in Kenya. Electricity is produced with an efficiency of 10–17% [10]. It appears likely that over the next 5–10 years, the growth rate of GE use for power generation will significantly increase [11].

Direct use of GE, as the name implies, involves using the heat in the water directly (without a heat pump or power plant) for such things as the heating of buildings, industrial processes, greenhouses, aquaculture (growing of fish) and resorts. Direct use projects generally use resource temperatures between 38

(100 °F) and 149 °C (300 °F) [3]. Lund and Freeston [12,13] have reviewed in detail the worldwide application of GE for direct utilization. They reported that an estimate of the thermal energy used at the beginning of 2000 is 190,699 TJ/year (52,972 GW h/year) and the distribution of the thermal energy used by category is approximately 42% for bathing and swimming pool heating, 23% for space heating (42,926 TJ/year), 12% for geothermal heat pumps, 9% for greenhouse heating, 6% for aquaculture pond and raceway heating, 5% for industrial applications, 2% for other uses, and less than 1% each for agricultural drying, snow melting, and air conditioning. Energy use growth in space heating since 1995 is 12%, or 2.3% annually. About 75% of the 42,926 TJ/year utilization is estimated for district heating, and the remainder for individual space heating. The majority of the district heating systems is in Europe, where the leaders are France and Iceland; the US, on the other hand, dominates individual home heating systems use, which is typical of Klamath Falls, Oregon and Reno, Nevada. Other countries with extensive district heating systems are China, Japan and Turkey. The share of Turkey in worldwide thermal energy use is about 12.10%.

Turkey is located in the Mediterranean sector of Alpine–Himalayan Tectonic Belt and has a place among the first seven countries of the world due to its abundance of geothermal resources. The share of its potential used is, however, only about 2–3%. This means that considerable studies on GE could be conducted in order to increase energy supply and reduce atmospheric pollution in Turkey [12]. The main uses of GE in Turkey are: space heating and domestic water supply, greenhouse heating, balneology, $CO_2$ and dry ice production, heat pumps and electricity generation [13].

The structure of the paper is as follows. The first section includes the introductory part; Section 2 briefly describes the historical development of GE worldwide; GE utilization in Turkey is presented in the third section, while Section 4 gives utilization opportunities of GE in the country; and the last section concludes.

## 2. A brief historical development of geothermal energy

Practical uses of GE for bathing, washing, and cooking purposes date back to prehistoric times. The Etruscans, Romans, Greeks, Indians, Chinese, Mexicans, and Japanese have all left evidence that they used hot water in ancient times. Since the Eighth century A.D., the Japanese have used thermal water for body purification. Besides this, the Romans used thermal springs for recreational purpose. In the Middle Ages, Arabs and Turks developed and diffused the traditional use of thermal baths, later known as Turkish baths. These uses were to lead the way to the modern balneological industry [11].

Barbier has comprehensively reviewed the historical development of GE worldwide. This development may be summarized as follows [8–13]:

- The earliest residential heating in the world by geothermal water was in Chaude Aigues, France in the 14th century.

- A prosperous boric acid industry was created in the Larderello area, Italy in 1818, where they extracted boric salts from the geothermal waters of the area, although mineral extraction from geothermal fluids is recorded from Etruscan times.
- Geothermal space heating was first installed in a house in Reykjavik (which is at present the only capital city in the world heated entirely by GE), Iceland, in 1909.
- Commercial generation of electricity from geothermal steam began in Larderello, Tuscany, Italy in 1913, with an installed capacity of 250 $kW_e$.
- Geothermal waters were first used in greenhouse heating in Iceland in the 1920s.
- The first municipal district heating system using geothermal water was set up in Reykjavik, Iceland, in 1930.
- Air conditioning using geothermal steam was first developed in a hotel in Rotorua, New Zealand, in the late 1960s.
- In 1972, deep well drilling technology improvements led to deeper reservoir drilling and access to more resources.
- In 1977, scientists developed the first hot dry rock reservoir at Fenton Hill, New Mexico.
- The first commercial-scale binary plant in the US, installed in Southern California's Imperial Valley, began operation in 1980.
- In 1991, the world's first magma exploratory well was drilled in the Sierra Nevada Mountains to a depth of 7588 ft. It did not encounter magma at that depth inside the caldera.
- In 1994, California Energy became the world's largest geothermal company through its acquisition of Magma Power. Near-term international markets gained the interest of US geothermal developers.
- In 2000, the installed capacity for power generation and direct uses worldwide was 7974 $MW_e$ and 15,145 $MW_t$, respectively.

As for a brief history of GE development in Turkey, before the 1960s, geothermal resources were only used spontaneously in bathing and medical treatment in Turkey. The General Directorate of Mineral Research and Exploitation (called MTA in Turkey) has carried out GE explorations in Turkey. Inventorial works and chemical analyses of hot springs and mineral waters started in 1962 [14]. Since then, the following evolution in time of GE development has occurred [15–25]:

- The first geothermal well was drilled in the Izmir-Balcova geothermal field in 1963.
- The Denizli–Kizildere geothermal field was discovered in 1963.
- The first space heating application by GE was in a hotel in Gonen-Balikesir in 1964.
- The first geological, geochemical, and geophysical studies were carried out with the support of the United Nations Development Program (UNDP) in the Denizli–Kizildere geothermal field in 1966.
- The investigations of GE in the country gained speed in the 1970s.

- A pilot power plant with a capacity of 0.5 $MW_e$ was installed in the Denizli–Kizildere geothermal field in 1974.
- The utilization of GE could not become sufficiently widespread due to scaling problems up to the early 1980s. Since then, important developments have been recorded in GE utilization.
- The Aydin geothermal field was discovered in 1982.
- The first downhole heat exchanger system was installed in Izmir-Balcova in 1983.
- The Denizli–Kizildere geothermal power plant, which is at present the only operating geothermal power plant in Turkey, was put into operation by the Turkish Electricity Establishment (renamed the Turkish Electricity Generation and Transmission Corporation, TEAS) in 1984.
- The first greenhouse heating system of 0.45 ha by GE was begun in Denizli–Kizildere geothermal field in 1985.
- In 1986, liquid $CO_2$ and dry ice production, which is the most well-known industrial application of GE, was started in a factory, adjacent to the Denizli–Kizildere geothermal power plant, with a capacity of 40,000 ton/year.
- The first experimental study on a geothermal (ground-source) heat pump with a horizontal loop configuration at the university level was carried out at the Mechanical Engineering Department, Middle East Technical University, Ankara, in 1986, while that with a vertical loop configuration was performed in the Solar Energy Institute, Ege University, Izmir, in 2000.
- Geothermal district heating applications started in 1987 in Turkey with the heating of 600 residences in Balikesir-Gonen.
- After 1990, geothermal direct-use applications increased as steeply as 185% from 1990 to 1995.
- The first residential geothermal heat pump system (or ground-source heat pump system) was installed in a villa with a floor area of 276 $m^2$ in Istanbul in 1998.

Recently, geothermal direct-use applications have reached up to 52,000 residence equivalent of geothermal heating, and engineering design of nearly 300,000 residence equivalents of geothermal district heating has been completed.

## 3. Geothermal energy utilization in Turkey

In Turkey, around 600 geothermal prospects and 170 geothermal fields with a temperature range of 40–242 °C have been discovered. The total proven geothermal electricity generation capacity is 200 $MW_e$, while the direct use capacity is 2046 $MW_t$. This proven potential increases by 5% annually with new exploration and drilling activities. The estimated geothermal power and direct use potential are reported as 4500 $MW_e$ and 31,500 $MW_t$, respectively. The potential for geothermal development in Turkey is generally considered large in terms of moderate and low temperature resources (<150 °C). Therefore, the resources are mostly suitable for direct use applications [26,27].

In the following, GE utilization in Turkey is studied in two categories, namely, electricity generation and direct uses. Direct or non-electric utilization of GE refers to the immediate use of the heat energy rather than to its conversion to some other form, such as electrical energy.

### *3.1. Electricity generation*

About 95% of the 170 geothermal fields in Turkey are low-medium enthalpy fields, which are suitable for direct use applications. Among the remaining nine fields, Denizli–Kizildere (200–242 °C), Aydin-Germencik (232 °C), Canakkale-Tuzla (174 °C), Aydin-Salavatli (171 °C), Kutahya-Simav (162 °C), Manisa-Salihli (150 °C) and Izmir-Seferihisar (153 °C) are high enthalpy field, which are suitable for electrical energy production [19,25,28]. The locations of the nine geothermal fields are illustrated in Fig. 1 [25], while the four fields of highest temperature are summarized below.

#### *3.1.1. The Denizli–Kizildere geothermal field*

As described in detail elsewhere [25], the only operating geothermal power plant of Turkey is the Denizli–Kizildere geothermal power plant (DKGPP), located near Denizli City in Western Anatolia with an installed capacity of 20.4 $MW_e$. The total capacity of the field is estimated to be 200 $MW_e$.

Studies of the geology, geophysics (gravity, resistivity, seismicity) and geochemistry and gradient drilling were carried out between 1965 and 1968. To date, a total of 20 deep wells varying in depth from 370 to 1241 m have been drilled, while the encountered temperatures were in the range of 170–212 °C [29].

The most significant characteristic of the field is the high amount of non-condensable gases (2.5% in the reservoir, 5% by volume of steam, 10–21% by

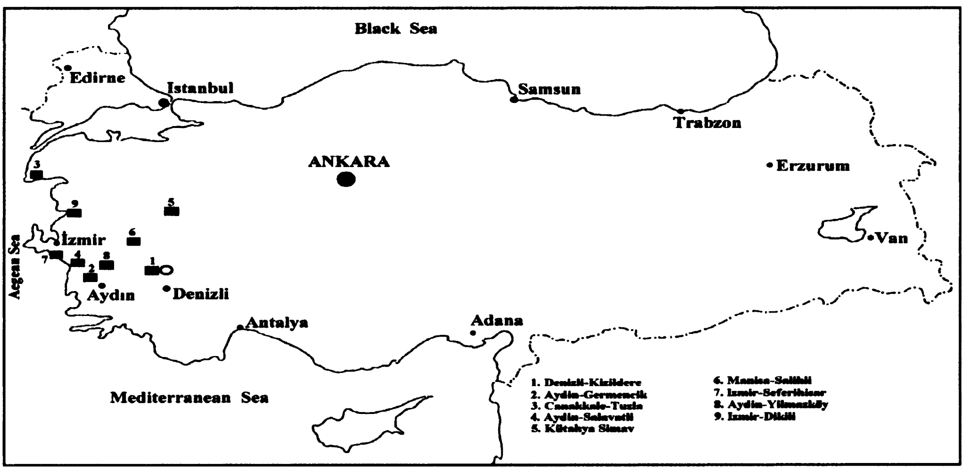


Fig. 1. Map indicating Turkey's geothermal fields suitable for power generation. (○) The location of Turkey's only operating geothermal power plant: the Denizli–Kizildere geothermal power plant [24].

weight of steam and average 13% by weight of steam at the turbine inlet), with a $CO_2$ content of 96–99%, $H_2S$ content of 100–200 ppm and $NH_3$ content of 72 ppm. A liquid $CO_2$ and dry ice production process with a capacity of 40,000 tons/year was built adjacent to the field in 1986. The capacity of the process was increased to 120,000 tons/year in 1999. Besides electricity and dry ice production, the resources of the field have also been used for greenhouse heating and space heating of offices and staff houses of the plant [25].

The electricity generation of the Denizli–Kizildere geothermal power plant between 1984 and 2001 is illustrated in Fig. 2 [25,30]. As can be seen in this figure, the plant produced on average an electrical energy of 84,920 MW h in the period between 1984 and 2002, representing an average electric power of 10.45 $MW_e$ in the same period.

Cerci has evaluated the performance of the Denizli–Kizildere geothermal power plant by using energy and exergy analysis [31]. The second law efficiency of the plant was found to be 20.8%, while the largest exergy destruction occurred from brine discharge to the Menderes River after flashing processes in the separators. It accounted for 46.9% of the total exergy input. He also concluded that a considerable amount of the exergy loss could be saved by implementing one of the two alternatives described in his study.

### 3.1.2. The Aydin-Germencik geothermal field

This Aydin-Germencik geothermal field, which is the second economical geothermal field for generating electricity, was discovered by the MTA. This field, where geothermal studies started in 1967, is located in the west of Buyuk Menderes Graben about 40 km from the Aegean Sea. To date, a total of nine exploration wells have been drilled varying in depths from 285 to 2398 m. The temperatures of the first and second aquifers were in the range of 203–214 and 216–232 °C, respectively [29]. The field capacity is estimated to be 100 $MW_e$. The first stage of the field development is planned to build a 25 $MW_e$ single flash plus binary power plant [32].

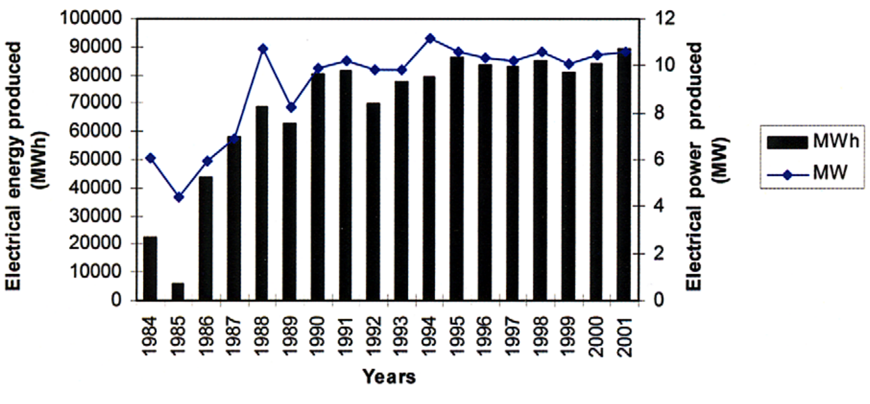


Fig. 2. Electricity generation of the Denizli–Kizildere power plant between 1984 and 2001 [25,30].

#### 3.1.3. The Canakkale-Tuzla geothermal field

The third field with power generation potential is the Canakkale-Tuzla field in northwest Anatolia. The first well was drilled in 1982, and the temperature encountered was 174 °C in a reservoir at a depth of 333–553 m in volcanic rocks. A second well was drilled to 1020 m. Temperatures up to 174 °C were recorded, but the permeability was low. Another two shallow wells with depths of 81 and 128 m also produced fluid at 146 and 165 °C [33].

#### 3.1.4. The Aydin-Salavatli geothermal field

This field is placed close to the central part of the Buyuk Menderes graben and at the same distance from the Denizli–Kizildere and Aydin-Germencik geothermal fields. Exploration wells with depths of 1510 and 962 m were drilled in 1987 and 1988, and their reservoir temperatures were 162 and 171 °C, respectively [29]. It was planned to build a 5 $MW_e$ binary or Kalina cycle plant in the field, but this has not been realized yet [34].

### 3.2. Direct use

Turkey is among the five leading countries in its geothermal direct use applications [35]. Turkey has significant potential for geothermal power production, possessing one-eighth of the world's total geothermal potential. Much of this potential is of relatively low enthalpy that is not suitable for electricity production but is still useful for direct heating applications [36]. Direct use of geothermal resources has expanded rapidly in the last 36 years from space heating of single buildings to district heating, greenhouse heating, industrial usage, modern balneology and physical treatment facilities [27].

Before the 1960s, geothermal resources were only used spontaneously in bathing and medical treatment in Turkey. The first space heating application by GE was in a hotel in Gonen-Balikesir in 1964. The first district heating system was built again in Gonen in 1987 with a capacity of 16.2 $MW_t$. Since then, direct use applications have significantly increased, as illustrated in Table 2 [27].

#### 3.2.1. Space heating

The total number of geothermal space heating systems is 37 [8,37]. Of this, large-scale, city-based geothermal district heating systems (LCGDHSs) account for 10. In the country, the district heating system applications were started with

Table 2
Development of direct use (excluding spas) installed capacity in Turkey [27]

| Year | Installed capacity ($MW_e$) |
|---|---|
| 1988 | 40.0 |
| 1990 | 45.5 |
| 1995 | 129.7 |
| 1998 | 354.6 |
| 2000 | 493.0 |
| 2002 | 540.0 |

LCGDHSs. In this regard, city-based geothermal district heating applications can be categorized into two groups, namely, (a) low temperature applications and (b) high temperature applications. There is one low temperature large-scale city heating application installed in Kirsehir, while high temperature applications are more numerous [22]. Table 3 shows a list of the city-based geothermal district heating systems installed in Turkey [17,18,22,34,37–46]. The city-based geothermal district heating systems considered have also been introduced in detail elsewhere [34,35,39,43,47–49].

### *3.2.2. Heat pumps*

Ground-source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs), are an attractive alternative to conventional heating and cooling systems owing to their higher energy utilization efficiency [50]. Lund and Freeston [12,13] have reported that GSHPs have had the largest growth since 1995, almost 59%, representing 9.7% annually. Most of this growth occurred in the US and Europe, though interest is developing in other countries such as Japan and Turkey. The installed capacity is 6875 $MW_t$, and the annual energy use was 23,287 TJ/year (6453 GW h/year) at the beginning of 2000 in 27 countries. It is estimated that the actual number of installed units is around 500,000, while the equivalent number of 12 kW units installed is slightly over 570,000. However, the data are incomplete. The 12 kW equivalent units installed are used as typical of homes in the US and some western European countries [51].

The studies performed on GSHPs in Turkey can be divided into three groups: (a) heat pump industry, (b) university studies, and (c) standardization studies.

The utilization of GSHPs in residential buildings is new in Turkey, although they have been in use for years in developed countries, and the performance of the components is well documented. In other words, GSHPs have been in the Turkish market since 1998. There are no Turkish GSHP manufactures yet. High-income earners also prefer these systems. To date, 207 units have been installed in the country, representing a total capacity of 3 MW. The majority of the installations are in the Marmara region of Turkey, with 140 units in the province of Istanbul [52]. Considering the ongoing installations, it appears that the growth rate will increase in the following years [16,53–57].

In the Turkish universities, limited experimental studies have been performed on GSHPs [58,59]. To date, four experimental systems have been installed, as illustrated in Table 4 [60–65].

Fourteen standards were also issued on heat pumps by the Turkish Standards Institution (TSE), of which only two pertained to water-to-water type heat pumps [66,67].

### *3.2.3. Greenhouses*

Greenhouse heating by GE is gaining more and more importance in Turkey. Over the last years, the strategical importance of food production and agricultural policies have stimulated a wide range of research and investigations on new methods for the exploitation of available GE for greenhouse heating in the country [68]. The

Table 3
City based geothermal district heating systems installed in Turkey [17,18,22,34,37–46]

| Location | Province | Capacity ($MW_t$) | Geothermal fluid temperature (°C) | Year commissioned | District heating distribution network supply/return temperature[a] (°C) | Installed capacity (residence)/number of dwellings heated | Type of pipe distribution line[b] |
|---|---|---|---|---|---|---|---|
| Gonen | Balikesir | 32 | 80 | June 1987 | – | 4500/3400 | Steel pipe system with two loops |
| Simav | Kutahya | 25 | 120 | October 1991 | 65/50 | 6500/3200 | Fiberglass reinforced polyester system with two loops is replaced by steel pipe system with three loops |
| Kirsehir[c] | Kirsehir | 18 | 54–57 | March 1994 | 48/42 | 1800/1800 | Steel pipe system with two loops |
| Kizilcahamam | Ankara | 25 | 80 | November 1995 | – | 2500/2500 | Steel pipe system with two loops |
| Balcova (Narlidere) | Izmir | 72 | 115 | October 1996 | 85/60 | 20,000/6697[d] (1593[d]) | Steel pipe system with three loops |
| Kozakli | Nevsehir | 11.2 | 90 | 1996 | – | 1250/1000 | Steel pipe system with two loops |
| Afyon | Afyon | 40 | 95 | October 1996 | 60/45 | 10,000/4000 | Steel pipe system with three loops |
| Sandilkli[e] | Afyon | 45 | 70 | March 1998 | 70/40 | 5000/1700 | Two loops, geothermal loop consisting of fiberglass reinforced polyester, district heating loop made of steel pipe |
| Diyadin[e] | Agri | 42 | 78 | September 1998 | 78/45 | 2000/1037 | Steel pipe system with three loops |
| Salihli | Manisa | 142 | 94 | March 2002 | 80/43 | 20,000/2250[f] | Feasibility and project completed, put into operation |

[a] Average values are given.
[b] In the system with two loops, a heat exchanger is used between the geothermal fluid and the district heating water, while in the system with three loops, a primary heat exchanger between the geothermal fluid and the district heating water, and a secondary heat exchanger between the district heating water and building substation are used.
[c] Peak load boiler is used.
[d] Total number of dwellings amounts to 14,400 residence equivalents, including hotels, official residences, the 9 September Hospital, the Economy University, etc.
[e] An integrated geothermal application system consisting of district heating, agriculture (greenhouse heating), bathing and balneology (thermal hotels), aquaculture (fish ponds), and industrial processes (liquefied carbon dioxide and precipitated calcium carbonate production).
[f] Target capacity.

Table 4
Main characteristics of GSHPs installed at Turkish universities as of December 2003 [60–65]

| Name of university (city) | Year built | System type | Heat pump capacity (kW) |
|---|---|---|---|
| Middle East Technical University (Ankara) [60] | 1986 | A single pipe–horizontal heat pump system for heating only with R-12; 10 m of ground coil at 1.5 m depth with a spacing of 0.6 m; COP: 1.1–1.3 | 0.95 |
| Ataturk University (Erzurum) [61] | 1999 | A water-to-water geothermal heat pump system for heating only with R-22; an actual COP value of 2.8; geothermal water inlet/outlet temperature 35/30 °C at a flow rate of 1100 l/h | 7.02 |
| Ege University (Izmir) [62–64] | 2000 | A GSHP system for both heating and cooling with a vertical single U-bend heat exchanger; 4.5 in. bore diameter with a boring depth of 50 m | 5.20 |
| Firat University (Elazig) [65] | 2002 | A GSHP system with horizontal heat exchanger for heating only with R-22; an actual COP value of 3.46 | 2.55 |

total area of greenhouses heated by GE is estimated to be about 36 ha, with a total heating capacity of 81 $MW_t$ for an average heat load of 2.25 $MW_t$/ha, as shown in Table 5 [69]. The majority of the geothermal heated greenhouses are in the Aegean region of Turkey. The growth rate of the geothermal greenhouse industry has increased in the last 3 years due to increases in fuel costs. The potential of new greenhouse development in the country is very large [19,69].

### *3.2.4. Industrial use*

Although many industrial and process applications of GE exist, the world's uses are relatively few. The oldest industrial use is at Lardarello, Italy, where boric acid and other borate compounds have been extracted from geothermal brine since 1790 [70]. Industrial applications and agricultural drying uses of GE are few in number in the US [71].

As for the uses in Turkey, the most well-known application is liquid $CO_2$ and dry ice production, with a plant with a capacity of 120,000 tons/year operating adjacent to the Denizli–Kizildere geothermal power plant since 1986. Another

Table 5
Greenhouse heating applications of GE in Turkey [69]

| Region | Area (ha) |
|---|---|
| Aegean | 25.66 |
| Interior Anatolia | 0.39 |
| Black Sea | 0.05 |
| South-eastern Anatolia | 9.37 |
| Marmara | 0.06 |
| East Anatolia | 0.20 |
| Mediterranean | – |
| Total | 35.73 |

industrial use in the region is in the textile industry, using the chemical properties of geothermal fluid as a whitening material. In Balikesir-Gonen, the wastewater of the district heating system has been used for the process hot water supply of 54 tanneries. There are two industrial productions, namely, liquefied carbon dioxide and precipitate calcium carbonate production, with capacities of 25 and 7000 tons/year, respectively, integrated with the Agri-Diyadin geothermal system [19,22,37,39].

## 4. Utilization opportunities of geothermal energy in Turkey

Parallel to the development of GE utilization in Turkey, it is projected that, by the years 2010 and 2020, the total installed capacity will increase to 3500 (500,000 residence equivalents, which is about 30% of the total residences in the country) and 8300 $MW_t$ (1,250,000 residence equivalents) for space heating and to 500 and 1000 $MW_e$ for power production, respectively [13,17].

To date, all geothermal district heating investments have been carried out by the governorship and municipalities. However, the private sector has expected to realize these investments as investors with the governorship and municipalities. Under Turkey's conditions, the share of the pipeline network in the geothermal district heating investments is about 70%, followed by production and reinjection wells at 10%, building adaptation at 10%, heating center at 5%, and engineering design at 5% [18,34].

Greenhouse heating, balneology, thermal tourism, electricity generation, $CO_2$ and dry ice production have a significant share of Turkey's GE utilization. Considering all geothermal applications in Turkey, a total direct GE utilization capacity of about 820 $MW_t$ is obtained. However, the possible GE potential of Turkey is about 31,500 $MW_t$. The potential of geothermal district heating systems in Turkey is given in Table 6, where a total of 678 $MW_t$ may be utilized. The current potential of wells according to their production values drilled for residential uses is listed in Table 7. Besides this, current geothermal applications and possible utilization opportunities of some geothermal areas in Turkey are given in Table 8.

As can be seen in this table, geofluid temperatures are in the range of 70–94 °C, representing potential for various GE applications such as industrial, district heating, etc. Main geothermal fields suitable for generating electricity and their possible utilization opportunities are also shown in Table 9, while capacities of geothermal heating systems in operation are given in Table 10. It is clear from these tables that most works should be performed to extend GE utilization throughout the country [72].

## 5. Conclusions

GE is a clean, proven, and reliable resource for supplying the needs of a sustainable society and helping to improve the global environment [73]. At present, Turkey is among the five leading countries in the world due to its geothermal direct use applications, while it is among the first seven countries as regards abundance of geothermal resources around the world. The main conclusions derived from the present study may be summarized as follows:

(a) Since Turkey is an energy importing country, GE has the potential to play an important role in the future energy supply of Turkey.
(b) There is no *geothermal law* in Turkey as yet. There is, however, a *geothermal law sketch*. It is expected that GE development will significantly speed up in the country if this law becomes effective.
(c) Although Turkey has no laws for the development of geothermal resources as yet and there is a lack of governmental support, direct use applications have been growing rapidly and proved by the public sector.
(d) GE offers technically and economically feasible possibilities for the development of different agricultural production sectors in Turkey.
(e) In Turkey, governmental investment in the energy sector is far behind the demand. To meet the fast growing demand, privatization and restructuring studies have started in the energy sector and the required legislation for private

Table 6
Geothermal district heating potential of Turkey [28]

| Item no. | Name of geothermal district | Potential ($MW_t$) |
|---|---|---|
| 1 | Balikesir–Gonen | 11.42 |
| 2 | Kutahya–Simav | 126.44 |
| 3 | Ankara–Kizilcahamam | 20.92 |
| 4 | Izmir–Narlidere + Balcova | 76.00 |
| 5 | Afyon–Sandikli | 32.47 |
| 6 | Kirschir | 45.15 |
| 7 | Afyon | 221.23 |
| 8 | Nevsehir–Kozakli | 57.65 |
| 9 | Agri–Diyadin | 87.04 |
| 10 | TOPLAM | 678.32 |

Table 7
Current potential of wells according to their production values drilled for residential uses [28]

| Item no. | Name of geothermal district | Potential ($MW_t$) |
|---|---|---|
| 1 | Afyon–Bolvadin | 18.93 |
| 2 | Afyon–Cobanlar | 7.16 |
| 3 | Afyon–Gazli Gol | 6.31 |
| 4 | Afyon–Omer Gecek | 220.20 |
| 5 | Afyon–Sandikli | 32.47 |
| 6 | Agri–Diyadin | 87.04 |
| 7 | Ankara–Kizilcahamam | 20.92 |
| 8 | Aydin–Alangullu | 0.55 |
| 9 | Aydin–Ilicabasi | 1.14 |
| 10 | Balikesir–Bigadic | 31.83 |
| 11 | Balikesir–Derman | 5.33 |
| 12 | Balikesir–Edremit | 10.33 |
| 13 | Balikesir–Gonen | 11.42 |
| 14 | Balikesir–Kizik | 1.82 |
| 15 | Balikesir–Pamukcu | 3.81 |
| 16 | Bursa–Tumbuldek | 3.68 |
| 17 | Canakkale–Hidirler | 0.10 |
| 18 | Canakkale–Kestanbol | 4.19 |
| 19 | Cankiri–Cavundur | 3.74 |
| 20 | Denizli–Golemezli | 5.65 |
| 21 | Denizli–Yenice | 20.60 |
| 22 | Diyarbakir–Cermik | 1.41 |
| 23 | Eskisehir–Sakariilice | 2.16 |
| 24 | Izmir–Aliaga | 20.43 |
| 25 | Izmir–Balcova | 67.67 |
| 26 | Izmir–Cesme–Ilica | 6.45 |
| 27 | Izmir–Dikili | 0.04 |
| 28 | Izmir–Narlidere | 1.84 |
| 29 | Izmir–Seferihisar | 6.25 |
| 30 | Kirsehir–Karakurt | 0.85 |
| 31 | Kirsehir–Terme | 45.15 |
| 32 | Kutahya–Gediz | 36.90 |
| 33 | Kutahya–Simav–Eynal | 117.92 |
| 34 | Kutahya–Simav–Nasa | 8.54 |
| 35 | Manisa–Alasehir–Kizildere | 0.35 |
| 36 | Manisa–Kula–Emir | 16.74 |
| 37 | Manisa–Kursunlu | 35.38 |
| 38 | Manisa–Saraycik–Borlu | 10.06 |
| 39 | Manisa–Urganli | 2.39 |
| 40 | Nevsehir–Kozakli | 57.65 |
| 41 | Nigde–Acigol | 12.89 |
| 42 | Nigde–Ciftehan | 0.26 |
| 43 | Rize–Ayder | 3.60 |
| 44 | Rize–Ikizdere–Ilice | 1.24 |
| 45 | Sakarya–Akyazi–Kuzuluk | 56.52 |
| 46 | Samsun–Havza | 10.60 |
| 47 | Tokat–Sulusaray | 2.09 |
| 48 | Van–Ercis–Sorkoy | 13.56 |
| 49 | Yalova–Armutlu | 2.83 |

Table 8
Current geothermal applications and possible utilization opportunities in Turkey [28]

| Item no. | Name of geothermal district | Temperature (°C) | Current geothermal applications | Possible utilization opportunities |
|---|---|---|---|---|
| 1 | Manisa–Kursunlu | 94 | Balneology, space heating | Balneology, space heating, drying, Salihli district heating |
| 2 | Nevsehir–Kozakli | 93 | Balneology, space and greenhouse heating | Balneology, space heating. drying, Kozakli district heating |
| 3 | Balikesir–Sindirgi–Hisaralan | 92 | Balneology, greenhouse heating | Balneology, greenhouse heating, industrial applications |
| 4 | Van–Ercis–Sorkoy | 92 | Balneology | Balneology, space heating |
| 5 | Denizli–Golemezli | 88 | Balneology, space and greenhouse heating | Balneology, space heating |
| 6 | Ankara–Kizilcahamam | 86 | Space heating | Space heating and other applications |
| 7 | Sakarya–Akyazi–Kuzuluk | 84 | Balneology, space heating | Balneology, space heating, drying, Akyazi district heating |
| 8 | Balikesir–Gonen | 82 | Balneology, space heating | Balneology, district and greenhouse heating, industrial applications |
| 9 | Agri–Diyadin | 78 | Balneology, space heating | Balneology, space and greenhouse heating, $CO_2$ production |
| 10 | Yalova–Armutlu | 77 | Thermal spring | Space heating and other applications |
| 11 | Yozgat–Sorgun | 75 | Thermal spring | Space heating and other applications |
| 12 | Afyon–Sandikli | 70 | Balneology, space heating | Balneology, space and greenhouse heating |

Table 9
Main geothermal fields suitable for generating electricity in Turkey and possible utilization opportunities [19,28,35]

| Item no. | Name of geothermal field | Temperature (°C) | Current utilization | Possible utilization opportunities |
|---|---|---|---|---|
| 1 | Afyon–Omer Gecek | 98 | Thermal facility heating | Thermal facility heating, district heating |
| 2 | Afyon–Sandikli | 70 | Thermal tourism, thermal facility heating | Thermal facility heating, thermal tourism, greenhouse heating |
| 3 | Agri–Diyadin | 78 | Simple balneology, space heating | Thermal tourism, thermal facility heating, greenhouse heating, $CO_2$ production |
| 4 | Ankara–Kizilcahamam | 86 | Space heating | Space heating and other applications |
| 5 | Aydin–Germencik | 232 | Greenhouse heating of 0.05 ha | Electricity generation, district heating and cooling, greenhouse heating, drying, textile industry, cold storage, thermal tourism, thermal facility heating |
| 6 | Aydin–Salavatli | 171 | Thermal tourism | Electricity generation, district heating and cooling, greenhouse heating, drying, industrial process heat, thermal tourism, thermal facility heating |
| 7 | Aydin–Yilmazkoy | 142 | Not available | Electricity generation plus integrated use |
| 8 | Balikesir–Bigadic | 98 | Thermal tourism, thermal facility heating | Thermal tourism, thermal facility heating, greenhouse heating |
| 9 | Balikesir–Gonen | 82 | Thermal tourism, thermal facility heating, space heating, industrial applications | Thermal tourism, thermal facility heating, district and greenhouse heating, industrial applications |
| 10 | Balikesir–Sindirgi–Hisaralan | 92 | Simple balneology applications, greenhouse heating (0.2 ha) | Thermal tourism, thermal facility heating, greenhouse heating, industrial applications |
| 11 | Canakkale–Tuzla | 174 | Greenhouse heating, space heating, simple balneology applications, salt production | Electricity generation, thermal tourism and thermal facility heating, salt production |
| 12 | Denizli–Golemezli | 88 | Simple balneology applications, greenhouse heating, thermal facility heating | Thermal tourism, thermal facility heating |
| 13 | Denizli–Kizildere | 242 | Electricity generation, greenhouse heating, space heating, simple balneology applications, $CO_2$ production, weaving industry | Electricity generation, building heating and industrial applications, drying, thermal tourism, thermal facility heating, cooling applications |
| 14 | Izmir–Aliaga | 96 | Not available | Thermal facility heating, thermal tourism |
| 15 | Izmir–Balcova | 125 | Thermal tourism, thermal facility heating, district heating, swimming pool and greenhouse heating | Thermal tourism, thermal facility heating, district heating, swimming pool and greenhouse heating |
| 16 | Izmir–Dikili | 130 | Simple balneology applications, greenhouse heating of 1 ha | Electricity generation plus integrated use |

| | | | | |
|---|---|---|---|---|
| 17 | Izmir–Seferihisar | 153 | Simple balneology applications, greenhouse heating of 0.6 ha at Seferihisar | Electricity generation, thermal tourism, thermal facility heating, district heating, greenhouse and industrial facility heating |
| 18 | Kutahya–Gediz | 97 | Thermal tourism, thermal facility heating | Thermal tourism, thermal facility heating, greenhouse heating |
| 19 | Kutahya–Simav | 162 | Thermal tourism, thermal facility heating, greenhouse heating of 12 ha, district heating of 3200 residences | Electricity generation, thermal tourism, thermal facility heating, greenhouse heating, industrial applications, district heating application at Simav, industrial use |
| 20 | Manisa–Kursunlu | 94 | Thermal tourism, thermal facility heating | Thermal tourism, thermal facility heating, drying, Salihli district heating |
| 21 | Manisa–Salihli–Caferbey | 150 | District heating application of 200 residences at Salihli | Electricity generation, thermal tourism, thermal facility heating, drying |
| 22 | Nevsehir–Kozakli | 93 | Balneology applications, space and greenhouse heating | Thermal tourism, thermal facility heating, Kozakli district heating |
| 23 | Sakarya–Akyazi–Kuzuluk | 84 | Thermal tourism, thermal facility heating | Thermal tourism, thermal facility heating, Akyazi district heating |
| 24 | Van–Ercis–Sorkoy | 92 | Simple balneology applications | Thermal tourism, thermal facility heating |
| 25 | Yalova–Armutlu | 77 | Balneology | Space heating and other applications |
| 26 | Yozgat–Sorgun | 75 | Balneology | Space heating and other applications |

Table 10
Capacities of geothermal heating systems in operation [72]

| District | Year | Temperature (°C) | Capacity of well (1/s) | Depth of well (m) | Current utilization |
|---|---|---|---|---|---|
| Adapazari–Akyazi | – | 84 | – | 2 × 250 | Thermal facility heating |
| Afyon–Arapderesi | – | 60 | 0.5 | – | – |
| Afyon–Gazligol | – | 51–67 | 1.4–3.5 | – | Balneology, thermal facility heating |
| Afyon–Heybeli | – | 56 | 2.1 | – | – |
| Afyon–Kizil Kilise | – | 57 | 6.4 | – | – |
| Afyon–Orucoglu | – | 43–48 | 252 | – | Thermal tourism, thermal facility heating |
| Afyon–Omer | 1996 | 90 | – | – | District heating of 4000 dwellings |
| Afyon–Omer Gecek | – | 50–105 | 5–100 | 9 × (125–250) | District heating, greenhouse heating, swimming pool heating |
| Afyoun–Sandikli | 1998 | 67–70 | 50 | – | Balneology, thermal facility heating, district heating |
| Afyon–Uyuzhamam | – | 75 | 10 | – | – |
| Aydin–Alangullu | – | 56–80 | 2–3.5 | – | – |
| Aydin–Bozkoy | – | 59 | 2 | – | – |
| Aydin–Camur | – | 90 | 2.2 | – | – |
| Aydin–Davutlar | – | 43 | 60 | – | – |
| Aydin–Germencik | 1982 | 232 | – | 1300–2398 | – |
| Aydin–Gumuskoy | – | 41 | 6 | – | – |
| Aydin–Ilicabasi | – | 85 | 12 | – | – |
| Aydin–Ortakci | – | 50 | 5 | – | – |
| Aydin–Omerbeyli | – | 203–232 | 25–159 | – | – |
| Aydin–salavatli | 1987 | 162–172 | 61–94 | 962–1510 | Electricity generation, heating |
| Ankara–Kizilcahamam | 1984 | 74 | – | 180 | Thermal tourism facility heating |
| | 1985 | 86–106 | – | 1556.5 | |
| | 1995 | 80–90 | – | – | District heating |
| Balikesir–Eksidere | – | 41 | 21 | – | – |

| | | | | | |
|---|---|---|---|---|---|
| Balikesir–Gonen | 1987 | 77–80 | 15–135 | – | District heating of 3400 dwellings, greenhouse of 0.2 ha, industrial heating |
| Balikesir–Gure | – | 53 | 3 | – | – |
| Balikesir–Havran | – | 59 | 3 | – | – |
| Balikesir–Hisaralari | – | 80–100 | 25–30 | – | – |
| Balikesir–Hisarkoy | – | 70–90 | 15–20 | – | – |
| Blikesir–Ivrindi | – | 42 | 4 | – | – |
| Blikesir–Kepekler | – | 54–58 | 8–15 | – | – |
| Blikesir–Manyas | – | 51 | 2.5 | – | – |
| Balikesir–Pamukcu | – | 54–60 | 3–40 | – | – |
| Balikesir–Samlidag | – | 62 | 1.5 | – | – |
| Balikesir–Yildiz | – | 47 | 1.5 | – | – |
| Bidis–Nemnu | 1986 | 250 | – | $2 \times 279$ | Dry vapor production |
| Bursa–Armutlu | – | 65–75 | 11–22 | – | – |
| Bursa–Cekirge | – | 45 | 20 | – | – |
| Bursa–Karamustafa | – | 80 | 15 | – | – |
| Bursa–Kemalpasa | – | 46–49 | 15–55 | – | – |
| Bursa–Orhaneli | – | 60 | 1 | – | – |
| Bursa–Oylat | – | 41 | 50 | – | Balneology, thermal facility heating |
| Canakkale–Can | – | 42–49 | 1.7–11 | – | |
| Canakkale–Hidirlar | – | 52–87 | 2–10 | – | – |
| Canakkale–Kara | – | 45 | 9 | – | – |
| Canakkale–Kestanbol | – | 73–75 | 5.25 | – | – |
| Canakkale–Kirkgecit | – | 52 | 3.5 | – | – |
| Canakkale–Kucukeepir | – | 41 | 6.5 | – | – |
| Canakkale–Ozencik | – | 65 | 10 | – | – |
| Canakkale–Tuzla | 1982 | 80–174 | 31–88 | 333–814 | Electricity generation, salt production |
| Denizil–Golemezli | – | 65 | 6 | – | – |
| Denizil–Kabaagac | – | 61 | 4 | – | – |

(continued on next page)

Table 10 (*continued*)

| District | Year | Temperature (°C) | Capacity of well (1/s) | Depth of well (m) | Current utilization |
|---|---|---|---|---|---|
| Denizil–Karahayn | – | 50–60 | 30–100 | – | Balneology, thermal facility heating |
| Denizil–Kizildere | 1968 | 85–200 | 10–400 | 20 × 669 | Greenhouse heating of 0.01 ha, electricity generation, dry ice production |
| | 1974 | – | – | – | |
| | 1984 | – | – | – | |
| Denizli–Tekkehamam | – | 85–116 | 15–30 | – | – |
| Denizil–Yenicc | – | 50 | 15 | – | – |
| Erzurum–Ilica | 1985 | 39 | – | 605–115 | Thermal facility heating |
| | 1986 | 39 | | | |
| Izmir–Aliaga | – | 58 | 5 | – | – |
| Izmir–Balcova | 1963 | 100–140 | 5–40 | (100–150) × 11 | District heating of 10,775 dwellings, greenhouse heating, thermal tourism, balneology |
| Izmir–Narlidere | 1996 | 120 | – | – | – |
| Izmir–Bayindir | – | 45 | 20 | – | – |
| Izmir–Bergama | – | 60 | 40 | – | – |
| Izmir–Cesme | – | 56–60 | 10–42 | – | |
| Izmir–Dikili | – | 55–100 | 1–150 | – | – |
| Izmir–Didilli | 1987 | 130 | – | 3 × 361 | – |
| | 1989 | 130 | – | – | |
| Izmir–Doganbey | – | 78–153 | 40–250 | – | – |
| Izmir–Kocaoba | – | 5.5 | 10 | – | |
| Izmir–Nebiler | – | 5.6 | 2.5 | – | – |
| Izmir–Pasa | – | 42 | 1 | – | – |
| Izmir–Seferihisar | 1983 | 153 | – | 1417–1948 | Thermal facility heating, greenhouse heating |
| | 1986 | 153 | – | – | |
| Izmir–Sifne | – | 42 | 12 | – | – |
| Izmir–Tavsanada | – | 5.8 | 5 | – | – |
| Kirsebir–Terme | – | 45–57 | – | – | District heating of 1800 dwellings |

| | | | | | |
|---|---|---|---|---|---|
| Konya–Acigol | – | 65 | – | – | Thermal facility heating |
| Kutahya–Cstgol | – | 46 | 97 | – | – |
| Kutahya–Dereli | - | 41 | 60 | – | – |
| Kutahya–Emet | – | 45 | 17 | – | Thermal facility heating, balneology |
| Kutahya–Eynal | 1985 | 75–147 | 3.5–150 | 2 × 150 | Balneology, thermal facility heating, greenhouse heating |
| Kutahya–Gediz | – | 77–98 | 35–120 | – | Balneology |
| Kutahya–Hamamkoy | – | 51 | 2 | – | – |
| Kutahya–Ilicakoy | – | 45 | 17 | – | – |
| Kutahya–Muratdagi | – | 41 | 9 | – | – |
| Kutahya–Nasa | – | 42–46 | 2.9 | – | – |
| Kutahya–Simav | 1987 | 162 | – | 725.2 | District heating of 6500 dwellings |
| Kutahya–Yenicckoy | – | 41 | 9 | – | – |
| Kutahya–Yoncali | – | 41–42 | 11–67 | – | – |
| Manisa–Kursunlu | – | 60–96 | 3–140 | – | – |
| Manisa–Mentese | – | 63 | 5.5 | – | – |
| Manisa–Salihli | 1990 | 155 | – | 1189.1 | Thermal tourism heating |
| Manisa–Saraycik | – | 51 | 5 | – | – |
| Manisa–Sart | – | 54 | 3 | – | – |
| Manisa–Sehitler | – | 59 | 3 | – | – |
| Manisa–Urganli | – | 70 | 13 | – | – |
| Mugla–Sultaniye | – | 41 | 10–10 | – | – |
| Mugta–Velibey | – | 41 | 10 | – | – |
| Nevsehir–Kozakli | – | 9 | – | 100 | Thermal facility heating |
| Rize–Hayder | – | 54 | – | – | Thermal facility heating |
| Samsun–Havza | – | – | – | – | Balneology |
| Sivas–Sicaxcermik | 1976 | 46.5 | – | – | Thermal facility heating, balneology |
| Usak–Banaz | – | 61 | 40 | – | – |
| Usak–Orencik | – | 41 | 20 | – | – |
| Van–Zilan | 1988 | 105 | – | 394.2 | District heating of 500 dwellings |
| Others | – | – | – | – | Greenhouse and thermal facility heating |

sector and foreign investment are arranged. The Electricity Market Law was enacted in March 2001 and the transition period was completed in September 2002. The Electricity Market Regulatory Agency (EMRA) is fully authorized to regulate the market and license activities. New financing mechanisms are also needed to promote investment in energy efficiency and renewable energy.

(f) Up-to-date information on GE utilization in Turkey could not be easily and completely found. Especially for city-based geothermal district heating systems and greenhouses, there were some differences between the data given by various researchers and companies. This means that, in general, good documented systems for GE should be established in the country.

(g) It should be underlined that is already confirmed and proven that GE can be commercially competitive with other energy sources.

(h) The main uses of GE cover a wide range of applications, such as space heating and domestic hot water supply, greenhouse heating, swimming and balneology, industrial processes, heat pumps, and electricity generation. Based upon the current status, the majority of geothermal application in Turkey have been realized in district heating systems.

(i) Turkey's geothermal resources are considerable, but they have not yet been systematically explored. Geothermal wells drilled to date in Turkey, which has 170 geothermal fields, are few in number. More geothermal wells should be drilled for extending geothermal applications throughout the country.

(j) Based on the values for wells drilled, Turkey's geothermal power production potential is estimated to be 764.81 $MW_e$.

(k) The only operating geothermal power plant of Turkey is the Denizli–Kizildere geothermal power plant with an installed capacity of 20.4 $MW_e$, while the total capacity of the field is estimated to be 200 $MW_e$.

(l) In Turkey, there are nine geothermal fields suitable for generating electricity.

(m) City-based geothermal district heating applications started in 1987 in Turkey. However, to date, their development has been relatively low.

(n) Heating by GE is the cheapest compared to conventional heating systems and has thereby gained wide acceptance among users in Turkey. Besides this, the cooling applications of GE are very limited in Turkey. Therefore, they should become widespread throughout the country.

(o) GSHPs are economically preferable to the conventional space heating/cooling systems used in Turkey. The primary barrier to marketing GSHP systems in Turkey is, however, the incremental cost of installing ground heat exchangers, which makes the total investment higher. There is customer resistance to GSHP technology in the country because Turkish heating systems differ in many respects from the US ones and the first installation cost of GSHPs is relatively high compared to the other conventional systems.

(p) The installation of GSHPs in Turkey has been growing rapidly over the past 2 years, reaching a total installed capacity of 3 MW.

(q) Industrial applications of GE are few in number in Turkey.

(r) In the implementation of the geothermal schemes in Turkey, optimization cri-

teria should be taken into account.

(s) One of the most important barriers preventing widespread use of renewables is the lack of a coherent national energy plan in which the role of renewables is well explained, as well as defining properties among alternatives.
(t) In the long term, GE will remain a viable option to furnish clean, reliable power in Turkey.
(u) Geothermal development offers a viable energy alternative to fossil fuel. However, environmental and social dimensions of geothermal development must be carefully and properly managed.

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